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Development of a Method to Test Holdover Times of Deicing and Anti-Icing Fluids in a Cold Room Using Artificially Generated Snow

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Final Report

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16. Abstract

A new method to test deicing fluids under laboratory conditions has been successfully demonstrated. This method generates artificial snow by grinding an ice core fed into a horizontally oriented rotating drill bit. The system is capable of producing snowfall rates from 5 to 50 gm/dm^2/hr over the area of a 30- × 50-cm frosticator plate. Since the snowfall rate can be accurately controlled, other variables such as temperature and fluid type can be varied independently in order to determine the dependence of failure time on each of the variables separately. The current version of the system produces failure times shorter than outdoor and indoor test results of the same fluid type under similar conditions. Preliminary analysis suggests that this may be due to the continuous nature of the snow generation method used in the current system compared to the intermittent snow application techniques used in previous tests.

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EXECUTIVE SUMMARY

A new method to test deicing fluids under laboratory conditions has been successfully demonstrated. This method generates artificial snow by grinding a snow core fed into a horizontally oriented rotating drill bit. The system is capable of producing snowfall rates from 5 to 50 $gm/dm^2/hr$ over the area of a 30- × 50-cm frosticator plate. Since the snowfall rate can be accurately controlled, other variables such as temperature and fluid type can be varied independently in order to determine the dependence of failure time on each of the variables separately. The current version of the system produces failure times shorter than outdoor and indoor test results of the same fluid type under similar conditions. Preliminary analysis suggests that this may be due to the continuous nature of the snow generation method used in the current system compared to the intermittent snow application techniques used in previous tests. This phenomenon along with enhanced control of temperature and snowfall rates are areas for follow-on investigations.

1. INTRODUCTION.

Current methods of establishing holdover times for deicing and anti-icing fluids under snow conditions involve outdoor testing using frosticator plates during snowstorms. While providing data on the performance of a particular fluid under actual snow conditions, this approach to testing can only be done during winter snow conditions, requiring considerable effort and expense. In addition, outdoor conditions are often highly unstable with variables such as wind speed and direction, temperature, and snowfall intensity changing rapidly. Thus, it is often difficult to compare tests from a particular snowstorm with tests conducted during other snowstorms and even within a particular storm, since particular conditions of snow intensity, wind speed and direction, and temperature are seldom duplicated. In contrast to outdoor testing, indoor testing in a cold room provides a well controlled environment in terms of temperature and wind (calm) and offers the opportunity of conducting testing year round. It also offers the opportunity of repeating tests to establish reliability and error tolerance limits and to develop functional relationships between variables by varying only one variable at a time. The lack of an appropriate method to generate realistic snow in sufficient quantities prevents testing of deicing and anti-icing fluids in cold rooms. Recent studies in Canada used natural snow collected from outdoors to perform testing in a cold room.

In this report, a method to generate artificial snow by mechanically shaving an ice core was undertaken. Section 2 presents the method of generating the artificial snow, and section 3 presents some preliminary results from holdover tests using frosticator plates with deicing and anti-icing fluids exposed to the artificial snow in the cold room. The holdover time results are compared to previous results. In section 4, the results are summarized and suggested avenues for future work are presented.

2. ARTIFICIAL SNOW GENERATION.

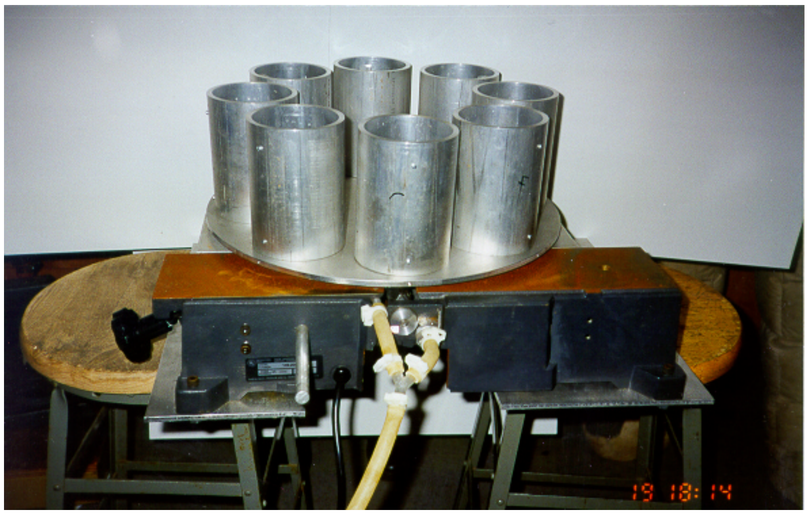
2.1 BASIC CONSIDERATIONS.

Natural snow occurs with a wide variety of sizes, shapes, and water content. This is due to the variety of temperatures and supersaturations that the snow crystals grow in and also due to their interaction with cloud droplets (collisions of snow crystals with cloud droplets leads to rime) and to the interaction of snow crystals with other snow crystals (collisions of snow crystals with other snow crystals lead to snowflakes consisting of 2 to 100 individual crystals). As a result, the density of an individual snowflake can vary from 0.01 to 0.3 gm/cm^3. Fall speeds of individual snow crystals vary from 10-100 cm/s, while the fall speed of snowflakes is remarkably constant with a value near 1 m/s at sea level. The nearly constant velocity of snowflakes is due to the fact that snowflake density typically decreases with increasing diameter.

2.2 SNOW FORMATION IN A COLD ROOM.

The processes of snow generation are clearly very complex and difficult to artificially reproduce in a cold room. However, it was observed that some of the basic characteristics of snowflakes (snow crystals aggregated together) can be fairly well simulated by shaving ice with a sharp instrument such as a knife or a drill. For instance, the fall speed and snow density of ice shavings produced mechanically with a sharp cutting edge are quite similar to the actual densities and fall velocity of natural snowflakes. This led to developing a method to generate snow using a sharp metal edge to shave an ice core. In the first attempt, a series of ice cores were fed into a small jointer (figure 1). Figure 1(a) shows the jointer with the eight ice core feed tubes. The ice core assembly rotated counter clockwise in the horizontal plane, feeding successive ice cores into the horizontally rotating jointer bit. Figure 1(b) shows the system with the ice core assembly removed. The jointer bit is located in the gap between the upper jointer surface. The air tubes feeding into the bit area were necessary to keep the ice chips from clogging the rotating bit. This method proved unsuccessful due to the difficulty in keeping the bit region clear of relatively coarse ice crystals.

(a)



(b)

FIGURE 1. INITIAL ICE GENERATION SYSTEM USING A JOINTER TO GENERATE ICE SHAVINGS. Figure (a) shows the complete system, while figure (b) shows the system with the ice core feed assembly removed.

The experience gained from this unsuccessful attempt was used to develop a second technique using a drill press in a horizontal orientation. A solid ice core, 6 cm in diameter and 44 cm long, was attached to a voltage-controlled feed system (between 5 and 15 volts) that translated the ice core into the rotating drill bit at a fixed rate. As the ice core is fed into the 7.5-cm-wide drill bit, ice shavings are produced. The ice core and drill press are mounted horizontally 2.0 m above the floor on a metal stand. The ice shavings fall to the ground and simulate a snowfall varying in intensity from 0.5 to 5 mm/hr or 5 to 50 $gm/dm^2/hr$. A photograph of the artificial snow generation system is shown in figure 2. A photograph of the system producing snow is shown in figure 3. The snow accumulation in a 30- $\times$ 50-cm pan located 1.2 m below the system is shown in figure 4. The density of this particular accumulation is 0.03 $gm/dm^2/hr$ and is fairly uniform in a horizontal plane. The artificial snowflakes range in size from 0.5 to 10 mm (figure 5).

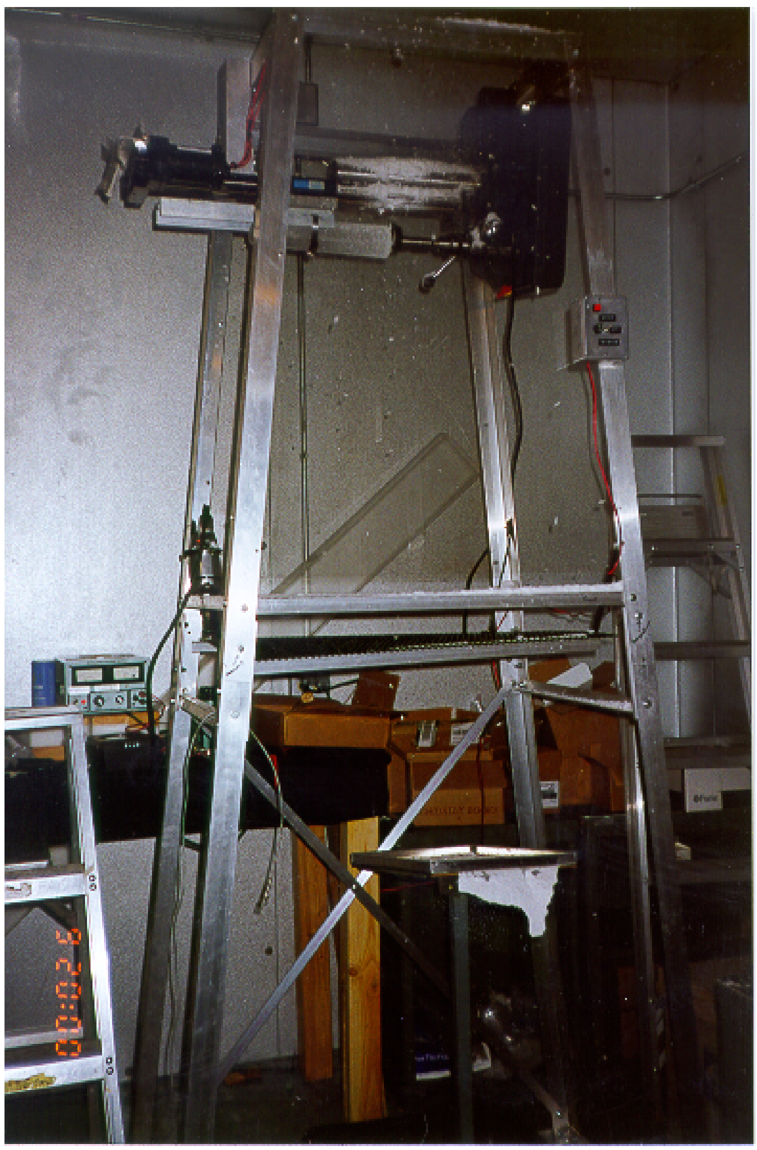


FIGURE 2. ARTIFICIAL SNOW GENERATION SYSTEM

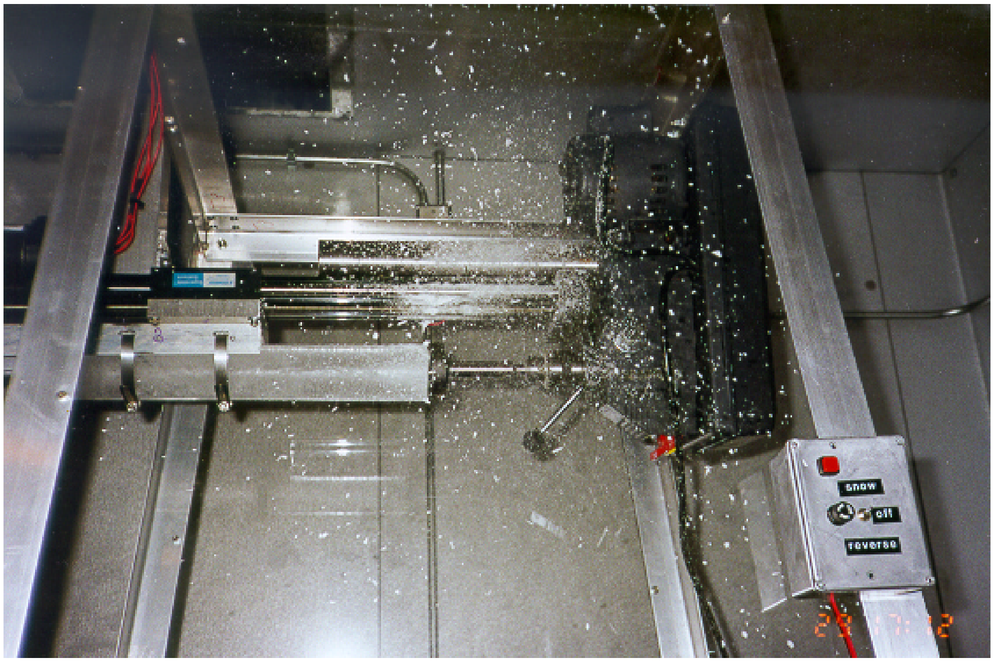


FIGURE 3. PHOTOGRAPH OF SYSTEM PRODUCING SNOW

FIGURE 4. SNOW ACCUMULATION IN A 30- × 50-cm PAN LOCATED 1.2 m BELOW THE SYSTEM

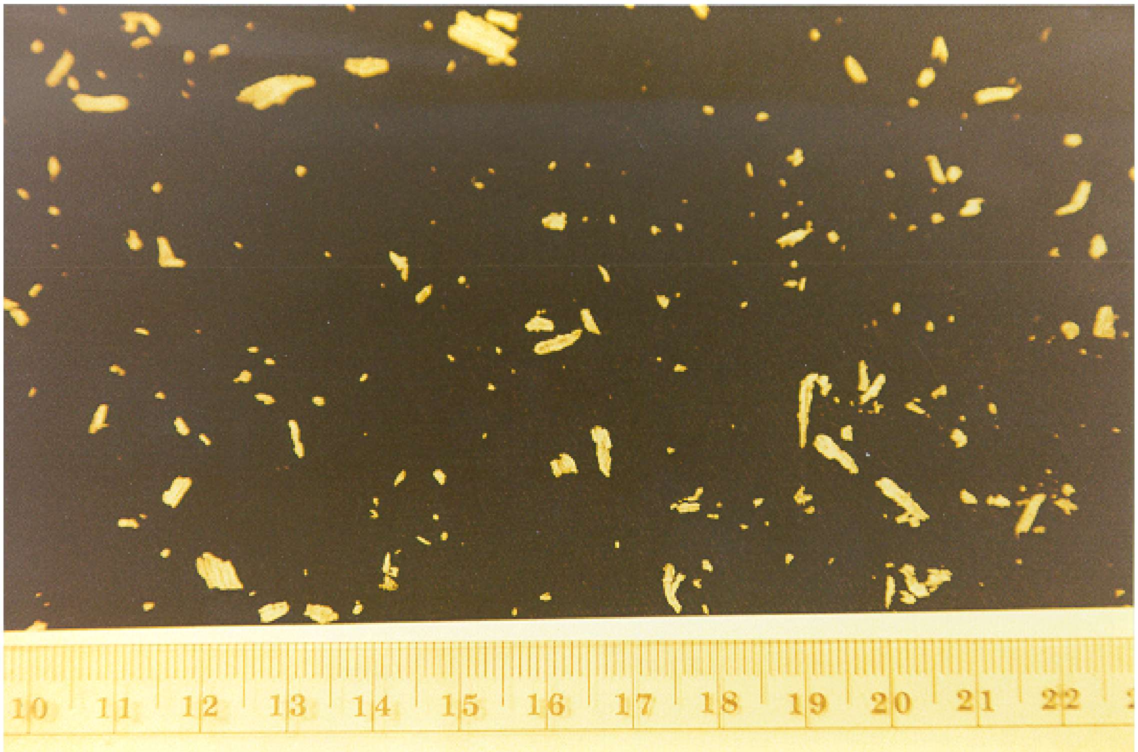


FIGURE 5. ARTIFICIAL SNOW PARTICLES. Scale given in centimeters, each small tick mark in millimeters.

The tests discussed in this report were all conducted at a cold-room temperature of -10°C ±2°C and under nearly calm wind conditions. A fan in the cold room circulated cold air near the top of the room; tests were conducted 0.8 m above the floor where the air motion was less than 1 m/s. The thermostat in the cold room cycled the cooler air approximately every 30 minutes, resulting in a temperature variation of ±2°C. Snowfall rates of 5.0 gm/dm^2/hr at the snow collection location 0.8 meters above the floor can be maintained by the system for over 2 hours without changing the ice core. At 25.0 gm/dm^2/hr, one ice core lasts 30 minutes. Figure 6 shows that the snowfall rate increases linearly with increased voltage to the feed motor. Currently the drill press rotation speed is kept at a constant rate of 1300 rpm. A plot of the snowfall accumulation as a function of time, determined by weighing the collection pan continuously, is shown in figure 7 for a constant 6 volts to the feed motor. Note that the snowfall rate starts at 1.2 mm/hr and gradually increases to near 1.6 mm/hr by the end of the 25-minute test. This increase is likely due to the motor and bearings warming up during the test. In the future, a feedback system that maintains the translator stage at a constant speed will be considered. While the increase in snowfall rate is undesirable, the current system can give reasonable estimates of holdover time if the snowfall rate is measured before and after each test and then averaged.

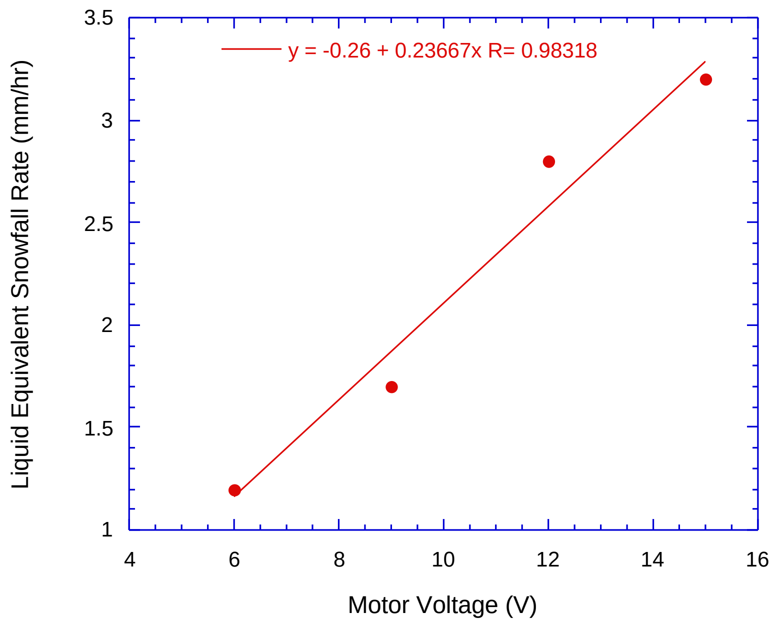


FIGURE 6. SNOWFALL RATE AS A FUNCTION OF MOTOR VOLTAGE
The 30- × 50-cm collection pan was located 1.2 m below the snow generator.

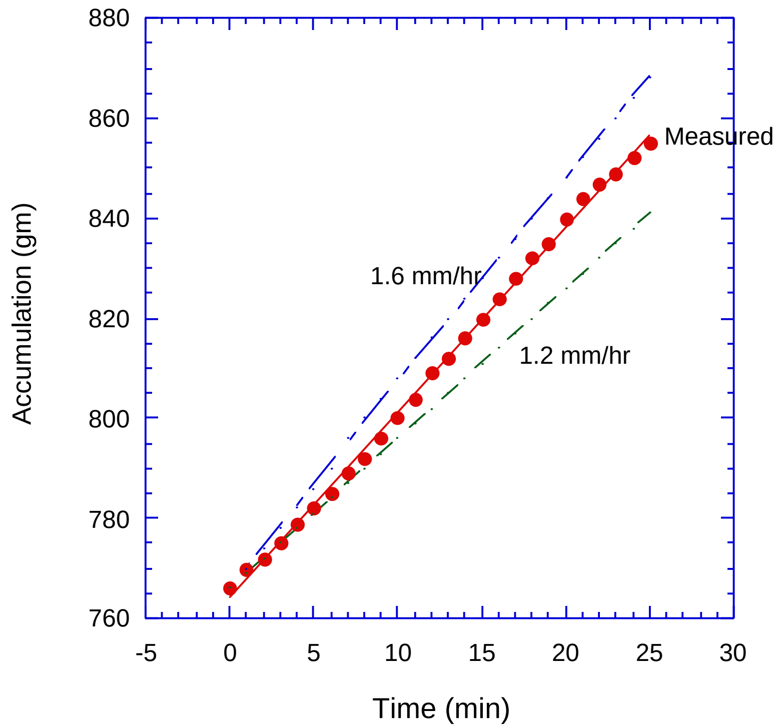


FIGURE 7. TOTAL MASS OF PAN PLUS SNOW AS A FUNCTION OF TIME DURING SNOWFALL GENERATION AT A CONSTANT 6 VOLTS (line with solid dots) Shown for comparison are the line's equivalent to a 1.6 mm/hr and a 1.2 mm/hr liquid equivalent accumulation.

The ice cores used as the source for the snow were created by freezing filtered, deionized water in plastic tubes with a 6 cm inner diameter and a length of 45 cm. The ice cores are stored in the same cold room where the tests are performed.

A shakable wire grid was installed 1 m below the snow generation point to more effectively disperse the snow horizontally. The grid elements in the mesh are a 2×1 cm ovals. The grid is shaken horizontally by a motor during snow production periods. The snow produced by this system has snow densities varying from 0.03 to 0.06 gm/cm^3, with the higher densities produced for the higher snowfall rates. These values of snow density are typical of dry snow conditions.

3. DEICING AND ANTI-ICING FLUID TESTS WITH THE ARTIFICIAL SNOW GENERATION SYSTEM.

3.1 RESULTS FROM THE ARTIFICIAL SNOW GENERATION SYSTEM EXPERIMENTS.

To demonstrate the system, frosticator panel tests in the cold room for Ultra+ Type IV neat anti-icing fluid were conducted at -10°C. The fluids were stored in the cold room and thus were at the same temperature as the ambient air. Table 1 gives the results of a series of tests with the Ultra+ fluid for precipitation rates varying from 0.5 to 3.5 mm/hr (5.0 to 35 gm/d^2/hr). The precipitation rate was determined by measuring the snowfall rate at the location of the frosticator plate for 10 minutes with a 30- × 50-cm pan just after the test using the same ice core. The precipitation rate at the end of the test was used as the test value. Figure 8a shows a photo of the test panel just after fluid application, and figure 8b shows the same panel after failure.

TABLE 1. RESULTS OF A SERIES OF TESTS WITH ULTRA+ NEAT FLUID FOR PRECIPITATION RATES VARYING FROM 0.5 TO 3.5 mm/hr (5.0 to 35 gm/dm^{2}hr)

Test No.	Precipitation Rate (mm/hr)	Failure Time (min)	Mass of Snow Accumulation (gm)
0	2.88	14	100
1	1.64	28	116
2	0.56	79	110
3	3.44	12	103
4	2.72	17	115
5	1.4	29	101
6	0.84	42	89

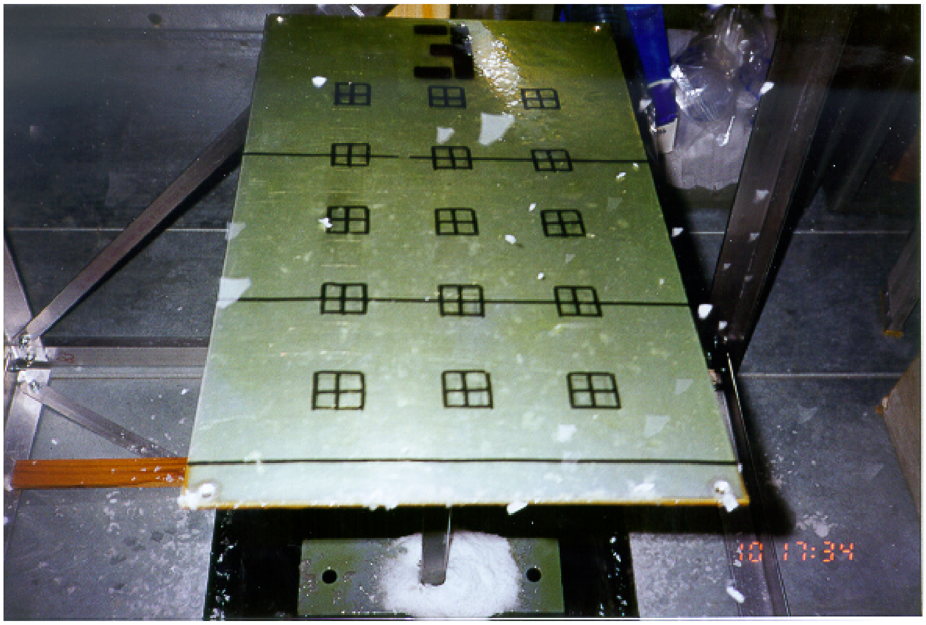


FIGURE 8a. FROSTICATOR PANEL JUST AFTER APPLICATION OF FLUID

FIGURE 8b. FROSTICATOR PANEL JUST AFTER FAILURE

The results of these tests; plotted in figure 9, show a clear inverse relationship between failure time and precipitation rate for a given temperature for this fluid. The curve fit to this data has a correlation coefficient of 0.986 and a power of -0.974, showing that the inverse relationship holds to a high degree. Figure 10 plots the same quantities on a log-log plot; the data has a linear relationship with a slope near -1.0, consistent with the inverse relationship mentioned above. Figure 11 plots the total accumulation versus the time of failure and shows that this particular fluid at this temperature fails at nearly the same mass of snow independent of the precipitation rate. Thus, the constant of proportionality is the total accumulation, resulting in the following for empirical relation failure time for this particular fluid at -10°C:

$$\text{Failure Time} \cong \text{Total Accumulation (gm)} / \text{Precipitation Rate (gm/min)}$$

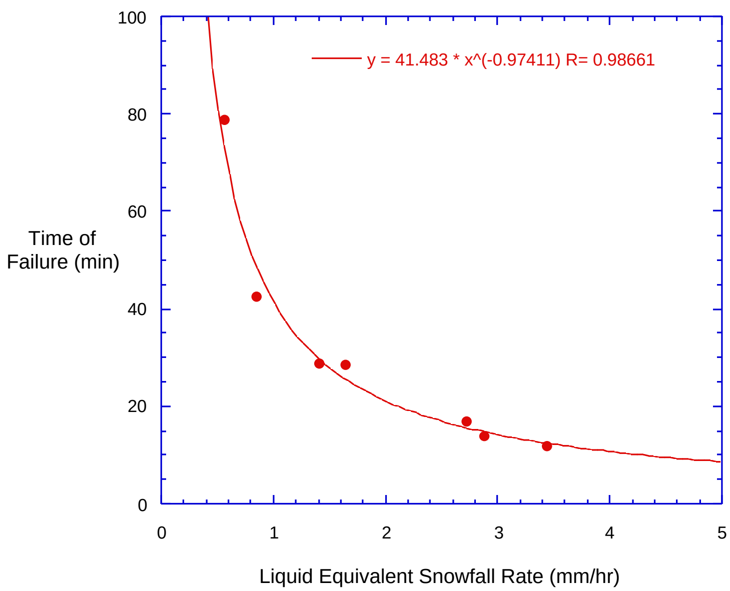


FIGURE 9. FROSTICATOR PANEL TESTS OF ULTRA+ TYPE IV NEAT FLUID AT -10°C FOR VARIOUS PRECIPITATION RATES USING THE ARTIFICIAL SNOW GENERATION SYSTEM. Power law curve fit shown in the upper portion of the plot.

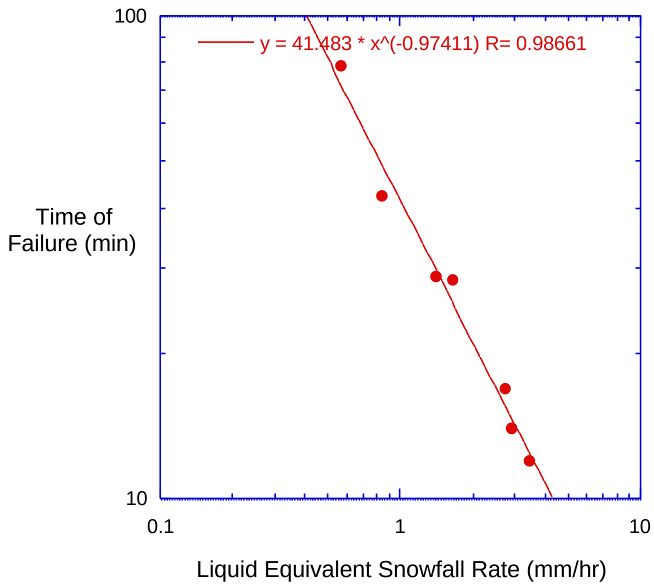


FIGURE 10. FROSTICATOR PANEL TESTS OF ULTRA+ TYPE IV NEAT FLUID AT -10°C FOR VARIOUS PRECIPITATION RATES USING THE ARTIFICIAL SNOW GENERATION SYSTEM PLOTTED ON A LOG-LOG SCALE

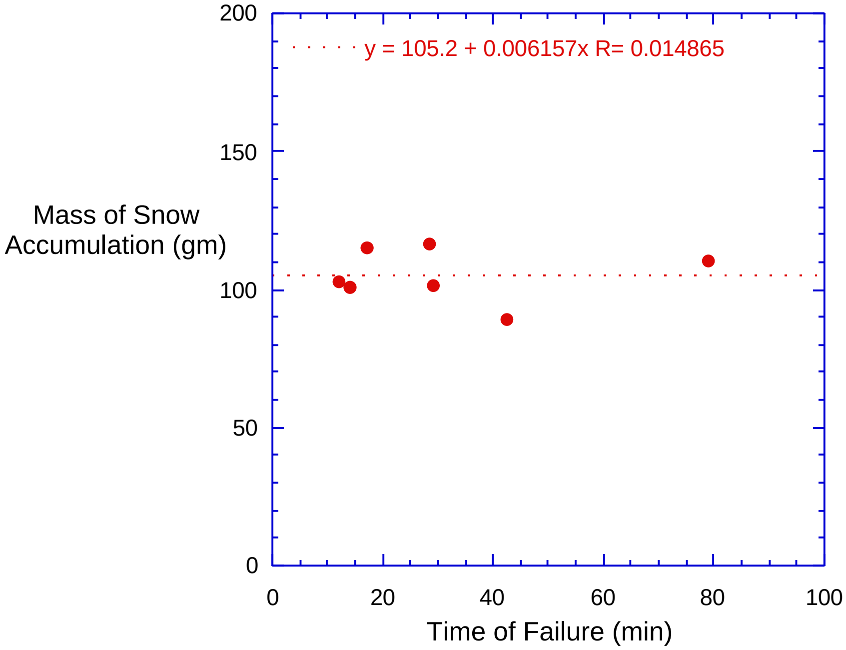


FIGURE 11. TOTAL MASS OF SNOW ACCUMULATION AT TIME OF FAILURE VERSUS THE TIME OF FAILURE

If a given fluid follows this relationship at a given temperature, then its failure can be characterized by the total accumulation, providing a simple comparison of fluid performance at a given temperature. For instance, if fluid A failed at a total snow accumulation of 100 gm at -10°C, while fluid B required 125 gm accumulation at -10°C before failure, then the failure time for fluid B would be 25 percent longer than fluid A at -10°C for all precipitation rates. The above empirical relation indicates that if the precipitation rate is doubled, then the failure time is cut in half. Thus, this implies that failure time at a given temperature is inversely proportional to the precipitation rate. If the above inverse relationship holds for all deicing and anti-icing fluids, it is postulated that only one test would be needed to determine the total accumulation required for the fluid to fail at a given temperature. The total accumulation could then be used to derive failure times for other precipitation rates using the equation above at a given temperature.

Currently, only Ultra+ Type IV at -10°C has been tested, and thus, verification of the above hypothesis will require further testing of different fluids at different temperatures. The results show, however, the power of conducting tests in a cold room in which many of the key variables can be controlled.

3.2 COMPARISON TO PREVIOUS DATA.

3.2.1 Comparison to National Center for Atmospheric Research (NCAR) Outdoor Tests of Ultra+ Type IV Neat Fluid.

Outdoor tests of Ultra+ Type IV neat fluid were conducted by NCAR during the winter of 1996-97. Thirty-one tests were conducted at temperatures between 0.0 and -3.8°C. These data are compared to the current indoor tests in figure 12. The failure times for the indoor test panels were substantially much shorter than for the outdoor tests. For example, the failure time at 20 gm/dm^2/hr occurred at 20 minutes for the indoor tests at -10°C, while at 70 minutes for the outdoor tests. It must be noted, however, that the outdoor tests were primarily conducted at temperatures close to 0°C, while the indoor tests were conducted at -10°C. Near 0°C the fluid would be expected to last longer than at -10°C due to the relatively warm temperature. In the following section, the current data are compared to the University of Quebec at Chicoutimi (UQAC) data in order to compare the current results at a more appropriate temperature range.

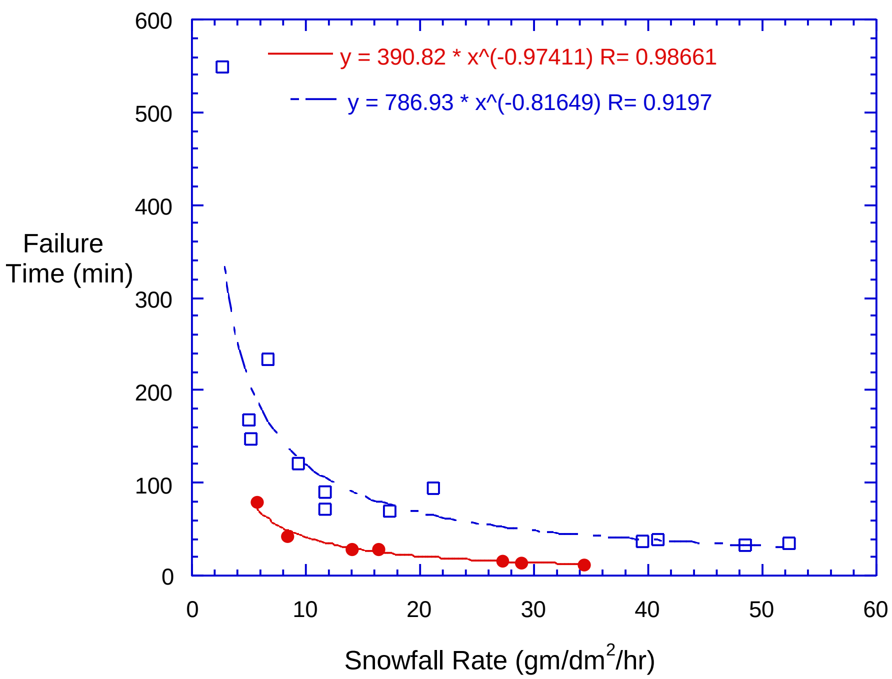


FIGURE 12. COMPARISON OF NCAR INDOOR AND OUTDOOR FROSTICATOR PLATE TESTS WITH ULTRA+ NEAT FLUID TYPE

3.2.2 Comparisons to UQAC Outdoor and Indoor Data.

In figure 13, UQAC outdoor test data of Ultra+ neat are compared to the current NCAR indoor tests. The UQAC data were obtained between a temperature range of -0.5 to -11.8°C and are thus closer to the NCAR indoor test conditions than the NCAR outdoor tests. These data were obtained from a recent report from UQAC. As can be seen, the comparison to the UQAC outdoor tests are much better than to the NCAR outdoor tests. For instance, at a snowfall rate of 20 gm/dm^2/hr, the failure time for the UQAC data is 40 minutes as compared to 20 minutes from the NCAR indoor data. However, the NCAR indoor failure times are still significantly shorter than the for outdoor tests. In order to further verify this result, the NCAR indoor tests are compared to UQAC indoor tests of Ultra+ neat at -10°C in figure 14.

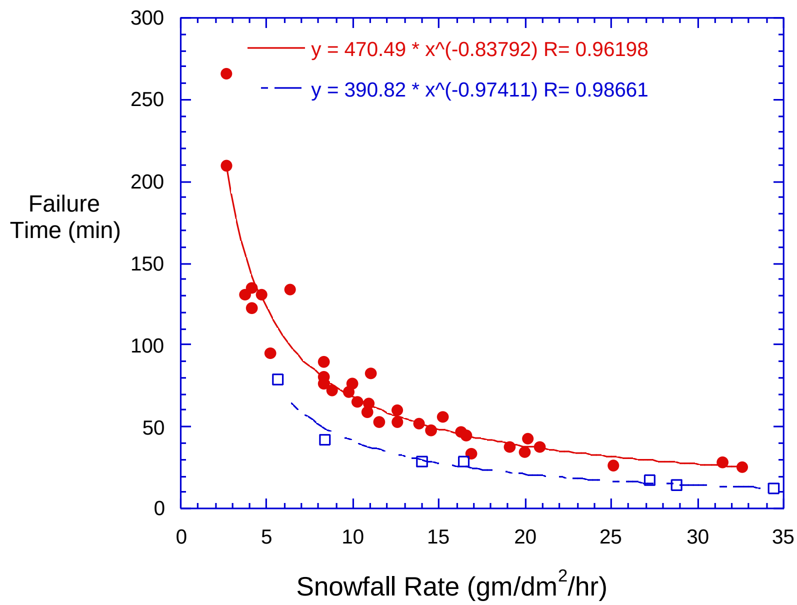


FIGURE 13. COMPARISON OF UNIVERSITY OF QUEBEC AT CHICOUTIMI (UQAC) OUTDOOR TESTS OF ULTRA+ NEAT (-0.5 TO -11.8°C) (SOLID DOTS) TO THE NCAR INDOOR TESTS AT -10°C (OPEN SQUARES)

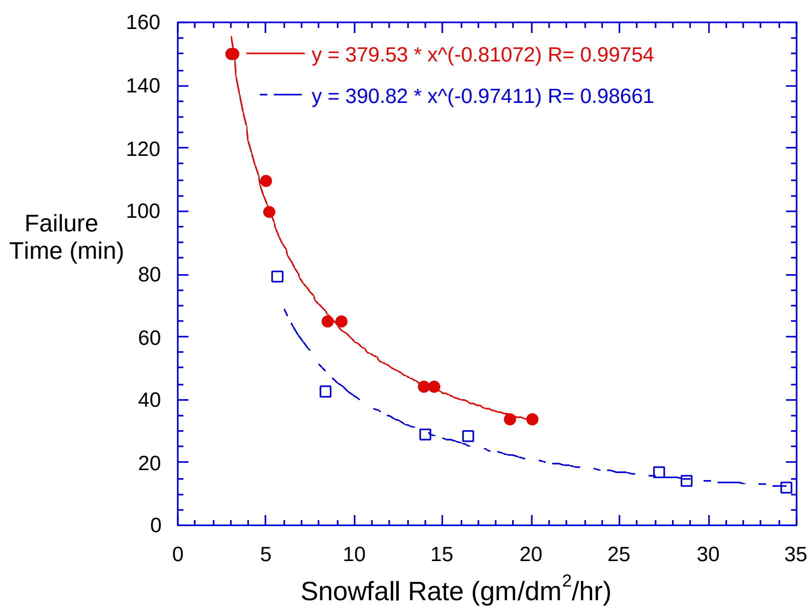


FIGURE 14. COMPARISON OF UQAC INDOOR TESTS OF ULTRA+ NEAT AT -10°C (SOLID DOTS) TO THE NCAR INDOOR TESTS OF ULTRA+ NEAT AT -10°C (OPEN SQUARES)

The UQAC indoor tests were conducted by sprinkling natural snow over the panels for 30 to 60 seconds, waiting for 2 to 5 minutes, and then repeating the process. This shows that the failure time of the UQAC tests are higher than for the NCAR indoor tests. Since the UQAC indoor test results compare favorably to their outdoor test results (figure 15), there seems to be a consistently lower failure time for the NCAR indoor tests.

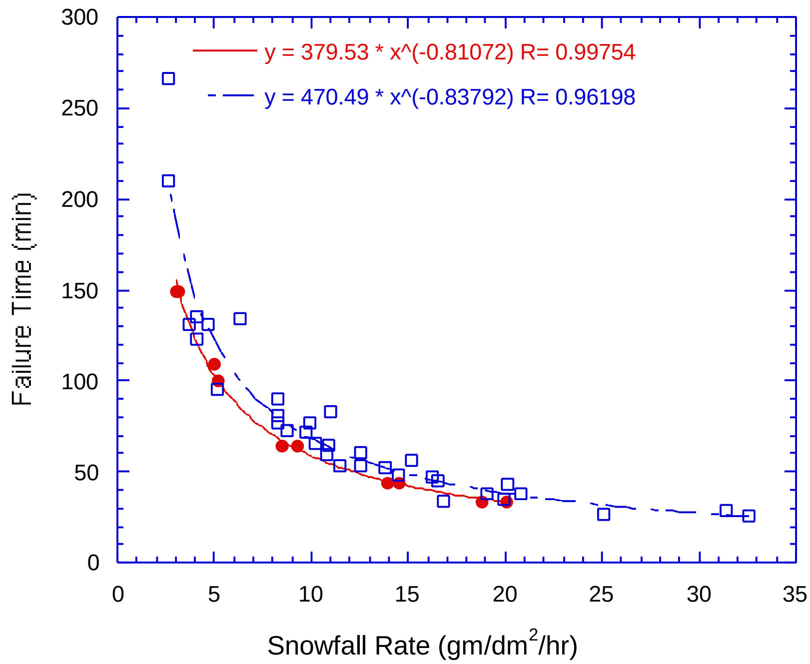


FIGURE 15. COMPARISON OF UQAC INDOOR TESTS OF ULTRA+ NEAT (OPEN SQUARES) WITH UQAC OUTDOOR TESTS OF ULTRA+ NEAT AT -10°C

A number of possibilities exist to explain this result. First, the NCAR tests produced a constant snowfall rate during the time period of the test, while the outdoor snowfall rates are highly variable. As mentioned above, the UQAC indoor tests were obtained by someone sprinkling snow over the fluid every 2 to 5 minutes for 30 seconds to 1 minute in order to simulate the desired snowfall rate. Since the NCAR snowfall simulation method is constant, the fluid does not have any time to recover, as may be the case in the UQAC indoor and outdoor tests. This lack of recovery time may lead to the shorter time in the NCAR indoor tests.

Preliminary tests were conducted with the artificial snow generation machine duplicating the snow dispersal method used by UQAC by turning the machine on for 1 minute and off for 2 minutes and conducting frosticator tests using this method and the continuous snow generation method under otherwise the same conditions. The results from this test duplicated the UQAC discontinuous snow results above and also the NCAR continuous results, suggesting that the current results are valid and that discontinuous snow dispersal methods may result in longer holdover times due to the fluid recovering during the nonsnow periods.

4. SUMMARY.

An artificial snow generation system has been developed that can generate snowfall rates between 5 and 50 gm/dm^2/hr over the area of a frosticator plate (30 $\times$ 50 cm). These rates can be maintained for up to 2 hours at 5 gm/dm^2/hr and for 30 minutes at 25 gm/dm^2/hr. The snow is generated by shaving an ice core fed into a horizontally oriented drill press. The feed rate is controlled by controlling the voltage to the translator motor.

Results to date show that the system can test deicing or anti-icing fluids for a wide range of liquid equivalent snowfall rates. Preliminary results also indicate that the failure time of a fluid can be shown to be inversely proportional to the liquid equivalent snowfall rate and that Ultra+ at -10°C may be characterized by a total snow accumulation that leads to failure of the fluid. Extension of this result to other fluids will require additional testing. The current results give shorter failure times for Ultra+ than NCAR outdoor tests and UQAC outdoor and indoor tests. Preliminary tests indicate that this may be due to the discontinuous snow application method producing longer times than the current continuous snow application method.